JC14 Rec'd PCT/PTO 0 6 DEC 2001

| FORM PTO-1390 (REV. 9-2001) U.S. DEPARTMENT OF COMMERCE PATENT AND TRADEMARK OFFICE **TRANSMITTAL LETTER TO THE UNITED STATES DESIGNATED/ELECTED OFFICE (DO/EO/US) CONCERNING A FILING UNDER 35 U.S.C. 371** | | ATTORNEY 'S DOCKET NUMBER 136.166 <br> U.S. APPLICATION NO. (If known, see 37 CFR 1.5 10/009199 |
|---|---|---|
| INTERNATIONAL APPLICATION NO. PCT/FR00/01593 | INTERNATIONAL FILING DATE 8 June 2000 (08.06.00) | PRIORITY DATE CLAIMED 09 June 1999 (09.06.99) |

TITLE OF INVENTION A METHOD FOR THE COLLECTIVE PRODUCTION OF MICROLENSES AT THE END OF A SET OF OPTICAL FIBRES OF THE FIBRE RIBBON TYPE

APPLICANT(S) FOR DO/EO/US
Monique Thual, Philippe Chanclou and Jean Lostec

Applicant herewith submits to the United States Designated/Elected Office (DO/EO/US) the following items and other information:

1. [X] This is a **FIRST** submission of items concerning a filing under 35 U.S.C. 371.
2. [ ] This is a **SECOND** or **SUBSEQUENT** submission of items concerning a filing under 35 U.S.C. 371.
3. [ ] This is an express request to begin national examination procedures (35 U.S.C. 371(f)). The submission must include items (5), (6), (9) and (21) indicated below.
4. [ ] The US has been elected by the expiration of 19 months from the priority date (Article 31).
5. [X] A copy of the International Application as filed (35 U.S.C. 371(c)(2))
   a. [ ] is attached hereto (required only if not communicated by the International Bureau).
   b. [X] has been communicated by the International Bureau.
   c. [ ] is not required, as the application was filed in the United States Receiving Office (RO/US).
6. [X] An English language translation of the International Application as filed (35 U.S.C. 371(c)(2)).
   a. [X] is attached hereto.
   b. [ ] has been previously submitted under 35 U.S.C. 154(d)(4).
7. [ ] Amendments to the claims of the International Aplication under PCT Article 19 (35 U.S.C. 371(c)(3))
   a. [ ] are attached hereto (required only if not communicated by the International Bureau).
   b. [ ] have been communicated by the International Bureau.
   c. [ ] have not been made; however, the time limit for making such amendments has NOT expired.
   d. [X] have not been made and will not be made.
8. [ ] An English language translation of the amendments to the claims under PCT Article 19 (35 U.S.C. 371 (c)(3)).
9. [X] An oath or declaration of the inventor(s) (35 U.S.C. 371(c)(4)). (unexecuted)
10. [ ] An English lanugage translation of the annexes of the International Preliminary Examination Report under PCT Article 36 (35 U.S.C. 371(c)(5)).

**Items 11 to 20 below concern document(s) or information included:**

11. [X] An Information Disclosure Statement under 37 CFR 1.97 and 1.98.
12. [ ] An assignment document for recording. A separate cover sheet in compliance with 37 CFR 3.28 and 3.31 is included.
13. [X] A FIRST preliminary amendment.
14. [ ] A SECOND or SUBSEQUENT preliminary amendment.
15. [X] A substitute specification, claims and abstract.
16. [ ] A change of power of attorney and/or address letter.
17. [ ] A computer-readable form of the sequence listing in accordance with PCT Rule 13ter.2 and 35 U.S.C. 1.821 - 1.825.
18. [ ] A second copy of the published international application under 35 U.S.C. 154(d)(4).
19. [ ] A second copy of the English language translation of the international application under 35 U.S.C. 154(d)(4).
20. [ ] Other items or information:

JC10 Rec'd PCT/PTO 06 DEC 2001

| U.S. APPLICATION NO. (if known, see 37 CFR 1.5) | INTERNATIONAL APPLICATION NO. | ATTORNEY'S DOCKET NUMBER |
|---|---|---|
| 10/009199 | PCT/FR00/01593 | 136.166 |

21. [x] The following fees are submitted:

**BASIC NATIONAL FEE (37 CFR 1.492 (a) (1) - (5)):**

| | CALCULATIONS | PTO USE ONLY |
|---|---|---|
| Neither international preliminary examination fee (37 CFR 1.482) nor international search fee (37 CFR 1.445(a)(2)) paid to USPTO and International Search Report not prepared by the EPO or JPO ........... **$1040.00** | | |
| International preliminary examination fee (37 CFR 1.482) not paid to USPTO but International Search Report prepared by the EPO or JPO ........ **$890.00** | | |
| International preliminary examination fee (37 CFR 1.482) not paid to USPTO but international search fee (37 CFR 1.445(a)(2)) paid to USPTO ........... **$740.00** | | |
| International preliminary examination fee (37 CFR 1.482) paid to USPTO but all claims did not satisfy provisions of PCT Article 33(1)-(4) .......... **$710.00** | | |
| International preliminary examination fee (37 CFR 1.482) paid to USPTO and all claims satisfied provisions of PCT Article 33(1)-(4) ............... **$100.00** | | |
| **ENTER APPROPRIATE BASIC FEE AMOUNT =** | $ 890.00 | |
| Surcharge of **$130.00** for furnishing the oath or declaration later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(e)). | $ | |

| CLAIMS | NUMBER FILED | NUMBER EXTRA | RATE | $ | |
|---|---|---|---|---|---|
| Total claims | 4 - 20 = | 0 | x **$18.00** | $ -- | |
| Independent claims | 1 - 3 = | 0 | x **$84.00** | $ -- | |
| MULTIPLE DEPENDENT CLAIM(S) (if applicable) | | | + **$280.00** | $ -- | |

| | | |
|---|---|---|
| **TOTAL OF ABOVE CALCULATIONS =** | $ 890.00 | |
| [ ] Applicant claims small entity status. See 37 CFR 1.27. The fees indicated above are reduced by 1/2. + | $ -- | |
| **SUBTOTAL =** | $ 890.00 | |
| Processing fee of **$130.00** for furnishing the English translation later than [ ] 20 [ ] 30 months from the earliest claimed priority date (37 CFR 1.492(f)). | $ -- | |
| **TOTAL NATIONAL FEE =** | $ 890.00 | |
| Fee for recording the enclosed assignment (37 CFR 1.21(h)). The assignment must be accompanied by an appropriate cover sheet (37 CFR 3.28, 3.31). **$40.00** per property + | $ | |
| **TOTAL FEES ENCLOSED =** | $ 890.00 | |
| | **Amount to be refunded:** | $ |
| | **charged:** | $ |

a. [x] A check in the amount of $ 890.00 to cover the above fees is enclosed.

b. [ ] Please charge my Deposit Account No. ______________ in the amount of $ __________ to cover the above fees. A duplicate copy of this sheet is enclosed.

c. [x] The Commissioner is hereby authorized to charge any additional fees which may be required, or credit any overpayment to Deposit Account No. 14-1080. A duplicate copy of this sheet is enclosed.

d. [ ] Fees are to be charged to a credit card. **WARNING:** Information on this form may become public. **Credit card information should not be included on this form.** Provide credit card information and authorization on PTO-2038.

**NOTE: Where an appropriate time limit under 37 CFR 1.494 or 1.495 has not been met, a petition to revive (37 CFR 1.137 (a) or (b)) must be filed and granted to restore the application to pending status.**

SEND ALL CORRESPONDENCE TO:

James E. Nilles
Nilles & Nilles, S.C.
Firstar Center, Suite 2000
777 East Wisconsin Avenue
Milwaukee, WI 53202
Telephone: 414-276-0977
Facsimile: 414-276-0982

James E. Nilles
SIGNATURE

James E. Nilles
NAME

16,663
REGISTRATION NUMBER

December 6, 2001

10/009199

JC10 Rec'd PCT/PTO 06 DEC 2001

#4/a

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

National Phase of PCT/FR00/01593

International Filing Date: 08 June 2000

Inventors: Monique Thual, Philippe Chanclou and Jean Lostec

Title: *A Method for the Collective Production of Microlenses at the End of a Set of Optical Fibres of the Fibre Ribbon Type*

Priority: French Application No. 99 07289; Filed 09 June 1999

Attorney Docket: 136.166 Customer No. 023907

PRELIMINARY AMENDMENT

DO/EO/US
Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

This Preliminary Amendment is directed to a new U.S. application as identified above. Please enter this preliminary amendment prior to calculating the fees.

Please substitute the attached specification, claims, and abstract (15 pages) and use the substitute application for examination purposes.

REMARKS

The substitute specification has been amended to insert headings and the Abstract has been amended to place it in conformance with preferred U.S. Patent Office practice. The substitute claims incorporate revisions made during international preliminary examination under Article 34, and are further amended to eliminate the multiple dependencies and the element numbers. A marked-up version of the changes made to the modified claims is attached and entitled *Version with Markings to Show Changes Made*.

Entry of the amendments and early consideration and allowance are respectfully requested.

Respectfully submitted,

James E. Nilles

James E. Nilles
Registration No. 16,663

Date: December 6, 2001

NILLES & NILLES, S.C.
Firstar Center, Suite 2000
777 East Wisconsin Avenue
Milwaukee, WI 53202
Telephone (414) 276-0977
Facsimile (414) 276-0982

ds G:\Data\CLIENT\136\166\PTO-PrelAmend.doc

10/009199
JC10 Rec'd PCT/PTO 06 DEC 2001

*Version With Markings to Show Changes Made*

CLAIMS

We claim:

1. A method for the collective production of microlenses at the end of a set of aligned optical fibres, characterised in that it comprises a step of heating the end face of the end of all the fibres [(F)] by means of an electric arc [(A)], the end face of the ends of the fibres being situated on this side of a line [(X)] of the hottest points of the electric arc and at a distance d from this line in order to round all the fibre ends homogeneously and simultaneously to obtain all the microlenses.

2. A method for the collective production of microlenses according to Claim 1, characterised in that the distance [(d)] between the front face of the ends of the optical fibres and the line [(X)] of the hottest points is between 850 micrometres and 950 micrometres.

3. A method for the collective production of microlenses according to Claim 1 [or 2], characterised in that the set of optical fibres consists of a ribbon [(10)].

4. A method for the collective production of microlenses according to Claim 3, characterised in that the ribbon comprises monomode fibres [(MO)] whose terminations comprise a length of silica [(SI)] welded to a length of fibre with an index gradient [(GRAD)], the microlenses [(L1, Ln)] being produced at the end of the lengths of fibres with an index gradient [(GRAD)].

# A METHOD FOR THE COLLECTIVE PRODUCTION OF MICROLENSES AT THE END OF A SET OF OPTICAL FIBRES OF THE FIBRE RIBBON TYPE

## BACKGROUND OF THE INVENTION

### 1. Field of the Invention

The invention relates to a method for the collective production of microlenses at the end of a set of optical fibres, of the ribbon of fibres type.

The present invention applies to optical and optoelectronic modules amongst other things for optical telecommunications. It applies more particularly to the production of microlenses on optical fibres in order to improve the coupling between optical and optoelectronic components. These microlenses are particularly well adapted to collective coupling with active components in arrays, such as lasers, semiconductor amplifiers, VCSELs or photodetectors for example.

### 2. Discussion of the Related Art

In the literature a large number of articles are found having methods for the individual manufacture of microlenses at the end of fibres which improve the coupling between active components and monomode fibres. The history of these microlenses is presented in the collection of publications "Microlenses Coupling Light to Optical Fibers", Huey-Daw Wu, Frank S. Barnes, 1991, pp. 149-213: "Microlenses Coupling Light to Optical Fibers" IEEE Lasers and Electro-optics Society 1991 [1].

On the other hand, very few articles are found concerning collective coupling lenses.

The most recent articles report on combinations of lengths of fibres of different natures and the fashioning of a lens at the end of fibres, but always in order to produce individual microlenses.

In fact, individual coupling lenses are known. Reference can be made to the article by K. Shiraishi et al. (University of Utsunomiya, Japan) "A fiber with a long working distance for integrated coupling between laser diodes and single-mode fibers", Journal of Lightwave Technology, Vol. 13 N° 8, pp. 1736-1744, August 1995 [2], which presents a lens whose working distance is 160 µm for laser-fibre coupling losses of 4.2 dB and lateral and angular axial positioning tolerances respectively of 35 µm, 2.6 µm and 0.8° for an additional loss of 1 dB. The results were obtained for a laser emitting at a wavelength of 1.49 µm with a mean total half-height divergence of 20.5° (that is to say 34° at $1/e^2$). This is a length of fibre 1 without a core and with a hemispherical end, welded to a monomode fibre 2 whose core has been locally enlarged by heat treatment, as shown by Figure 1.

In a more recent article, Shiraishi and Hiraguri "A lensed fiber with cascaded Gi-fiber configuration for efficient coupling between LDs to single-mode fibers" ECOC '98, 20-24 September, Madrid Spain, pp. 355-356 [5], propose a new lens consisting of two lengths of monomode fibres, of different natures, whose focusing parameters are different, welded together and

to a monomode fibre by electric arc. A hemispherical profile is conferred on the end multimode fibre by means of an electric arc welder. Losses of 2 dB are obtained in front of a laser diode emitting at 1.3 µm, whose total divergence in far field at half-height of the maximum is 24.9° x 19.5° (that is to say 42.2° x 33.1° at $1/e^2$). The working distance is 50 µm.

If the publications concerning individual fibre laser coupling lenses are numerous, those dealing with collective lenses intended for multichannel optical modules are more rare.

A method is known which consists in interposing an array of microlenses (not fixed to the fibre ribbons). By way of example, the coupling lens shown in Figure 2 of G. Nakagawa and al. (Fujitsu Laboratories, Japan) "Highly efficient coupling between LD array and optical fiber array using Si microlens array" IEEE Photonics Technology Letters, Vol. 5, N° 9, pp. 1056-1058, September 1993 [4], makes it possible to obtain 4.8 ± 0.3 dB by dynamic coupling between the array 4 of four lasers with a total half-height divergence of 30° (that is to say 44° at $1/e^2$) and 4 monomode fibres $2_1$, 2n by means of a matrix of silicon lenses. This type of coupling complicates the assembly steps, since it adds an additional component to be positioned very precisely.

In 1996, J. Le Bris "High performance semiconductor array module using tilted ribbon lensed fibre and dynamical alignment" ECOC '96 Oslo THc.2.3, p. 4.93, from the company Alcatel (AAR, France)

proposes a lensing method on a fibre ribbon which consists of chemically etching a ribbon of monomode fibres and reworking the end of each fibre of the ribbon by electric arc. With this method 3.6 dB of loss is obtained in front of an array of semiconductor amplifiers with ribbons misaligned by 20 x 25° of total half-height divergence (that is to say 34 x 42.5° at $1/e^2$). The wavelength is 1.55 µm.

The recommended solutions for the "lensing" of the fibres (the fitting of lenses at the end of fibres) which make it possible to obtain good coupling levels are not collective methods in the case of references [1] to [3].

In addition, the outside diameter of the 125 µm fibre is not maintained all along the microlens, which poses a problem for the hybridisation on a silicon platform in precise positioning Vs and for precision ferrule fitting.

For the collective methods known at the present time, the coupling losses are still too high. In addition, the use of discrete lenses described in reference [4] requires several successive alignments, which increases the number of assembly steps compared with microlenses attached at the end of the fibre. The method described in reference [5] also imposes a very short working distance of less than 15 µm in addition to the fact that it is complex.

## SUMMARY OF THE INVENTION

The purpose of the present invention is to improve the coupling between an array of active elements and a set of aligned fibres of the fibre ribbon type.

To this end, the invention relates to a method for the collective production of microlenses at the end of a set of aligned optical fibres, principally characterised in that it comprises a step of heating the end of all the fibres by means of an electric arc in order to form the microlenses, the plane in which the ends of the fibres are situated being distant from the line of hottest points of the electric arc in order to round their end evenly.

The method according to the invention also has the advantage of being collective and therefore compatible with mass production, and with a very high performance.

According to another characteristic of the invention, the distance between the optical fibre ends and the line of hottest points is between 850 micrometres and 950 micrometres.

Advantageously, the set of optical fibres consists of a ribbon.

According to a preferred embodiment of the invention, the ribbon comprises monomode fibres whose terminations comprise a length of silica welded to a length of fibre with an index gradient, the microlenses being produced at the end of the lengths of fibres with an index gradient.

## BRIEF DESCRIPTION OF THE DRAWINGS

Other advantages and particularities of the invention will emerge clearly from a reading of the description which is made below and which is given by way of non-limitative example with regard to the drawings, in which:

- Figure 1 depicts an individual coupling lens according to the state of the art,
- Figure 2 depicts a collective coupling lens according to the state of the art,
- Figure 3 depicts the outline diagram of the production method according to the invention,
- Figure 4 depicts the diagram of a "lensed" ribbon of fibres according to the method in accordance with the invention,
- Figure 5 illustrates a photograph of a "lensed" ribbon according to the invention.

The method according to the invention consists in rounding the end of a set of fibres being in the majority of applications in the form of a ribbon of fibres 10, by means of an electric arc welder, only the electrodes of which are depicted at E1, E2, the ribbon 10 being placed far from the line X of the hottest point so that the ends of the fibres of the ribbon are aligned at a distance d of around one millimetre (typically 900 µm) with respect to this hot point, in order to be placed on an isotherm. This makes it possible, unlike the "lensing" at the hot point of the electrodes E1, E2, to obtain a hemispherical shape which is not only homogeneous over all the fibres of

the ribbon, but also not to modify the diameter of the fibres.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

According to a preferred embodiment, the method is applied to the production of hemispherical lenses with a microlens as described in the patent EP 0 825 464 of the applicant.

The patent EP 0 825 464 relates to a collective microlens known as GRADISSIMO since it consists of lengths of multimode fibres with an index gradient GRAD and silica SI welded successively together and to a ribbon of monomode fibres MO, referenced 10 in Figure 4.

The invention consists of collectively "lensing" the end of this microlens.

The losses are 2.5 ± 0.05 dB in front of 60° x 50° of total divergence in far field of $1/e^2$ of the maximum intensity for working distances of 100 ± 5 µm, instead of 10.5 dB for 15 µm of working distance in front of a cleft monomode fibre.

The losses are 1.4 ± 0.05 dB in front of lasers of 21° x 21° of total divergence in far field at $1/e^2$ of the maximum intensity for working distances of 100 ± 5 µm, instead of 3.2 dB for 15 µm of working distance in front of a cleft monomode fibre.

For this example application, the method consists in first producing the microlens ribbon 10 known as "GRADISSIMO" by collective welding and cleaving of lengths of fibres with an index gradient and silica on

a ribbon of monomode fibres as described in the patent EP 0 825 464.

This ribbon is then placed, in the same collective welder as the one used for producing the "GRADISSIMO" ribbon, typically at 900 µm from the normal welding position on the optical axis. This is possible through the control (optional) which makes it possible to control the motors and the arc of the welder by RS232 interface. An electric arc is then sent, and makes it possible to round the end of the lengths of fibres with an index gradient as illustrated in Figures 3 and 4.

The diameter of the hemisphere depends on the electric arc/fibre distance and the electrode discharge current.

By way of example the Sumitomo type T62 welder was used.

Then there was obtained collectively a ribbon of microlenses which is hereinafter referred to as "SUPERGRADISSIMO", having a hemispherical end as illustrated in Figures 4 and 5 making it possible to improve the coupling level in front of arrays of active components such as lasers, semiconductor amplifiers or photodiodes for example.

The fibres being situated far from the hot point, only the core of the fibre with a gradient index is melted so that the outside diameter of 125 µm is maintained over the entire length of the microlens, including at its end.

Here are a few example embodiments from a ribbon with 4 channels F1, F2, F3, F4:

Example 1

The coupling of a "supergradissimo" ribbon was effected in front of a BRS laser with a wavelength 1.301 µm of 60° x 50° of total divergence in far field at $1/e^2$ of the maximum intensity.

The measuring conditions were as follows:

T° = 21°C, polarisation current I = 42 mA, reference power of the laser 10,000 µW.

The results are illustrated by the following table:

| Channel (1 fibre = one channel) | Welding losses silica/ index gradient (dB) | Length of silica (µm) | Welding losses (silica/ monomode) | Length of index gradient (µm) | Radius of hemisphere (µm) | Coupling losses (dB) | Working distance (µm) |
|---|---|---|---|---|---|---|---|
| F1 | 0.06 | 544.00 | 0.04 | 357.19 | 68 | 2.56 | 53.5 |
| F2 | 0.02 | 546.50 | 0.03 | 358.00 | 68 | 2.59 | 54.3 |
| F3 | 0.07 | 546.12 | 0.02 | 354.45 | 68 | 2.55 | 53.3 |
| F4 | 0.03 | 546.12 | 0.05 | 357.19 | 68 | 2.52 | 54.2 |

Example 2

The coupling of a "supergradissimo" ribbon was effected in front of a BRS laser 1.310 µm of 21° x 21° of total divergence in far field at $1/e^2$ of the maximum intensity.

The measuring conditions were as follows:

T° = 22°C, polarisation current I = 72.6 mA, reference power of the laser 10,000 µW.

The results are illustrated by the following table:

| Channel | Welding losses silica/ index gradient (dB) | Length of silica (μm) | Welding losses (silica/ monomode) | Length of index gradient (μm) | Radius of hemi-sphere (μm) | Reflectivity at end of fibre (dB) | Coupling losses (dB) | Working distance (μm) |
|---|---|---|---|---|---|---|---|---|
| F1 | 0.05 | 275.00 | 0.05 | 279.00 | 82 | -39.3 | 1.45 | 102.40 |
| F2 | 0.04 | 275.00 | 0.02 | 281.00 | 80 | -40.1 | 1.41 | 107.60 |
| F3 | 0.03 | 274.50 | 0.06 | 281.00 | 83 | -41.9 | 1.38 | 107.80 |
| F4 | 0.04 | 274.00 | 0.02 | 282.00 | 81 | -39.3 | 1.42 | 105.00 |

By way of comparison, because of its rounded profile, the reflectivity measured at the end of the fibre by means of a reflectometer of the WIN-R type from Photonétics is typically -40 dB instead of -14.7 dB for a cleft fibre.

In addition, the great working distance limits the power reinjected into the laser diode after reflection on the fibre. This is very important for applications of the semiconductor amplifier type or lasers with external cavities for which the stray reflections interfere with the functioning.

A low-cost collective "lensing" method has just been described which makes it possible to improve the coupling between the arrays of active components and ribbons of monomode fibres compared with the prior art (up to 1.5 dB of losses) for large working distances (up to 100 μm). And this in a homogeneous manner over ribbons of fibres, it being understood of course that this is merely an example with 4 channels.

The applications of the invention in the field of telecommunications fit just as well in distribution networks for their collective and low cost aspect and in transmission networks because of their high coupling

performances and their low reflectivity level. The large working distances which they offer are an advantage for all applications, and are in fact less critical to position and greatly reduce the influence of Fresnel reflections.

Reference can be made to the table annexed to the description which illustrates results obtained for the radius of the spheres as a function of the distance between the fibre ribbon and the hot point of the electrodes E1, E2, the current sent to the electrodes in arbitrary units and the electrode discharge time. The margin indicated for each radius corresponds to the scattering of the values on the ribbon.

| Sample N° | Distance ribbon/ electrodes (µm) | Current (µ.a) | Electrode discharge time | Radius of hemisphere (µm) |
|---|---|---|---|---|
| 298 | 920 | 60 | 7 | 82 ± 5 |
| 297 | 920 | 60 | 7 | 80 ± 5 |
| 302 | 920 | 60 | 6 | 95 ± 5 |
| 288 | 910 | 60 | 5 | 110 ± 5 |
| 293 | 910 | 60 | 7 | 80 ± 5 |
| 285 | 910 | 59 | 7 | 90 ± 5 |
| 277 | 910 | 60 | 4 (3 impacts) | 75 ± 5 |
| 287 | 910 | 58 | 5 (2 impacts) | 80 ± 5 |
| 295 (ex.2) | 900 | 60 | 6 | 82 ± 5 |
| 294 | 900 | 60 | 6 | 90 ± 5 |
| 290 | 900 | 60 | 7 | 85 ± 5 |
| 292 | 900 | 60 | 8 | 90 ± 5 |
| 291 | 900 | 59 | 9 | 85 ± 5 |
| 296 | 900 | 60 | 6 (2 impacts) | 78 ± 5 |
| 287 | 890 | 56 | 5 | 110 ± 20 |
| Test | 890 | 55 | 3 | 100 ± 30 |
| Test | 850 | 63 | 5 | 75 ± 5 |
| 286 (ex.1) | 840 | 63 | 5 | 68 ± 0 |
| Test | 830 | 63 | 5 | 70 ± 5 |
| Test | 730 | 63 | 5 | Not homogeneous |
| Test | 400 | 50 | 2 | Not homogeneous |
| Test | 350 | 45 | 3 | No rounded part |
| Test | 300 | 50 | 2 | Not homogeneous |
| Test | 200 | 50 | 2 | Not homogeneous |
| Test | 200 | 30 | 2 | No rounded part |
| Test | 20 | 50 | 2 | Large lenses not homogeneous |

Beams are obtained with a hemispherical end of between 68 and 110 µm with a homogeneity of ± 5 µm on the 4 channels of the ribbon for distances between hot point and ribbon ranging from 830 to 920 µm. Ribbons 286 and 295 are the subject of embodiments presented respectively in Examples 1 and 2.

CLAIMS

We claim:

1. A method for the collective production of microlenses at the end of a set of aligned optical fibres, characterised in that it comprises a step of heating the end face of the end of all the fibres by means of an electric arc, the end face of the ends of the fibres being situated on this side of a line of the hottest points of the electric arc and at a distance d from this line in order to round all the fibre ends homogeneously and simultaneously to obtain all the microlenses.

2. A method for the collective production of microlenses according to Claim 1, characterised in that the distance between the front face of the ends of the optical fibres and the line of the hottest points is between 850 micrometres and 950 micrometres.

3. A method for the collective production of microlenses according to Claim 1, characterised in that the set of optical fibres consists of a ribbon.

4. A method for the collective production of microlenses according to Claim 3, characterised in that the ribbon comprises monomode fibres whose terminations comprise a length of silica welded to a length of fibre with an index gradient, the microlenses being produced at the end of the lengths of fibres with an index gradient.

## ABSTRACT OF THE DISCLOSURE

A method for the collective production of microlenses at the end of a set of aligned optical fibres. The method consists in heating the end of all the fibres by means of an electric arc in order to form the microlenses, the plane in which the ends of the fibres are situated being distant from the line of the hottest points in the electric arc in order to round their end homogeneously. Useful for making optical and optoelectric modules.


**G:\Data\CLIENT\136\166\App-Amended.doc**

10/009199
JC10 Rec'd PCT/PTO 06 DEC 2001

21 PRTS



*015161.PC - FT134*
*Text as published*



# A METHOD FOR THE COLLECTIVE PRODUCTION OF MICROLENSES AT THE END OF A SET OF OPTICAL FIBRES OF THE FIBRE RIBBON TYPE

The invention relates to a method for the collective production of microlenses at the end of a set of optical fibres, of the ribbon of fibres type.

The present invention applies to optical and optoelectronic modules amongst other things for optical telecommunications. It applies more particularly to the production of microlenses on optical fibres in order to improve the coupling between optical and optoelectronic components. These microlenses are particularly well adapted to collective coupling with active components in arrays, such as lasers, semiconductor amplifiers, VCSELs or photodetectors for example.

In the literature a large number of articles are found having methods for the individual manufacture of microlenses at the end of fibres which improve the

coupling between active components and monomode fibres. The history of these microlenses is presented in the collection of publications "Microlenses Coupling Light to Optical Fibers", Huey-Daw Wu, Frank S. Barnes, 1991, pp. 149-213: "Microlenses Coupling Light to Optical Fibers" IEEE Lasers and Electro-optics Society 1991 [1].

On the other hand, very few articles are found concerning collective coupling lenses.

The most recent articles report on combinations of lengths of fibres of different natures and the fashioning of a lens at the end of fibres, but always in order to produce individual microlenses.

In fact, individual coupling lenses are known. Reference can be made to the article by K. Shiraishi et al. (University of Utsunomiya, Japan) "A fiber with a long working distance for integrated coupling between laser diodes and single-mode fibers", Journal of Lightwave Technology, Vol. 13 N° 8, pp. 1736-1744, August 1995 [2], which presents a lens whose working distance is 160 µm for laser-fibre coupling losses of 4.2 dB and lateral and angular axial positioning tolerances respectively of 35 µm, 2.6 µm and 0.8° for an additional loss of 1 dB. The results were obtained for a laser emitting at a wavelength of 1.49 µm with a mean total half-height divergence of 20.5° (that is to say 34° at $1/e^2$). This is a length of fibre 1 without a core and with a hemispherical end, welded to a monomode fibre 2 whose core has been locally enlarged by heat treatment, as shown by Figure 1.

In a more recent article, Shiraishi and Hiraguri "A lensed fiber with cascaded Gi-fiber configuration for efficient coupling between LDs to single-mode fibers" ECOC '98, 20-24 September, Madrid Spain, pp. 355-356 [5], propose a new lens consisting of two lengths of monomode fibres, of different natures, whose focusing parameters are different, welded together and to a monomode fibre by electric arc. A hemispherical profile is conferred on the end multimode fibre by means of an electric arc welder. Losses of 2 dB are obtained in front of a laser diode emitting at 1.3 µm, whose total divergence in far field at half-height of the maximum is 24.9° x 19.5° (that is to say 42.2° x 33.1° at $1/e^2$). The working distance is 50 µm.

If the publications concerning individual fibre laser coupling lenses are numerous, those dealing with collective lenses intended for multichannel optical modules are more rare.

A method is known which consists in interposing an array of microlenses (not fixed to the fibre ribbons). By way of example, the coupling lens shown in Figure 2 of G. Nakagawa and al. (Fujitsu Laboratories, Japan) "Highly efficient coupling between LD array and optical fiber array using Si microlens array" IEEE Photonics Technology Letters, Vol. 5, N° 9, pp. 1056-1058, September 1993 [4], makes it possible to obtain 4.8 ± 0.3 dB by dynamic coupling between the array 4 of four lasers with a total half-height divergence of 30° (that is to say 44° at $1/e^2$) and 4 monomode fibres $2_1$, 2n by means of a matrix of silicon lenses. This type of

coupling complicates the assembly steps, since it adds an additional component to be positioned very precisely.

In 1996, J. Le Bris "High performance semiconductor array module using tilted ribbon lensed fibre and dynamical alignment" ECOC '96 Oslo THc.2.3, p. 4.93, from the company Alcatel (AAR, France) proposes a lensing method on a fibre ribbon which consists of chemically etching a ribbon of monomode fibres and reworking the end of each fibre of the ribbon by electric arc. With this method 3.6 dB of loss is obtained in front of an array of semiconductor amplifiers with ribbons misaligned by 20 x 25° of total half-height divergence (that is to say 34 x 42.5° at $1/e^2$). The wavelength is 1.55 µm.

The recommended solutions for the "lensing" of the fibres (the fitting of lenses at the end of fibres) which make it possible to obtain good coupling levels are not collective methods in the case of references [1] to [3].

In addition, the outside diameter of the 125 µm fibre is not maintained all along the microlens, which poses a problem for the hybridisation on a silicon platform in precise positioning Vs and for precision ferrule fitting.

For the collective methods known at the present time, the coupling losses are still too high. In addition, the use of discrete lenses described in reference [4] requires several successive alignments, which increases the number of assembly steps compared

with microlenses attached at the end of the fibre. The method described in reference [5] also imposes a very short working distance of less than 15 µm in addition to the fact that it is complex.

The purpose of the present invention is to improve the coupling between an array of active elements and a set of aligned fibres of the fibre ribbon type.

To this end, the invention relates to a method for the collective production of microlenses at the end of a set of aligned optical fibres, principally characterised in that it comprises a step of heating the end of all the fibres by means of an electric arc in order to form the microlenses, the plane in which the ends of the fibres are situated being distant from the line of hottest points of the electric arc in order to round their end evenly.

The method according to the invention also has the advantage of being collective and therefore compatible with mass production, and with a very high performance.

According to another characteristic of the invention, the distance between the optical fibre ends and the line of hottest points is between 850 micrometres and 950 micrometres.

Advantageously, the set of optical fibres consists of a ribbon.

According to a preferred embodiment of the invention, the ribbon comprises monomode fibres whose terminations comprise a length of silica welded to a length of fibre with an index gradient, the microlenses

being produced at the end of the lengths of fibres with an index gradient.

Other advantages and particularities of the invention will emerge clearly from a reading of the description which is made below and which is given by way of non-limitative example with regard to the drawings, in which:

- Figure 1 depicts an individual coupling lens according to the state of the art,
- Figure 2 depicts a collective coupling lens according to the state of the art,
- Figure 3 depicts the outline diagram of the production method according to the invention,
- Figure 4 depicts the diagram of a "lensed" ribbon of fibres according to the method in accordance with the invention,
- Figure 5 illustrates a photograph of a "lensed" ribbon according to the invention.

The method according to the invention consists in rounding the end of a set of fibres being in the majority of applications in the form of a ribbon of fibres 10, by means of an electric arc welder, only the electrodes of which are depicted at E1, E2, the ribbon 10 being placed far from the line X of the hottest point so that the ends of the fibres of the ribbon are aligned at a distance d of around one millimetre (typically 900 μm) with respect to this hot point, in order to be placed on an isotherm. This makes it possible, unlike the "lensing" at the hot point of the electrodes E1, E2, to obtain a hemispherical shape

which is not only homogeneous over all the fibres of the ribbon, but also not to modify the diameter of the fibres.

According to a preferred embodiment, the method is applied to the production of hemispherical lenses with a microlens as described in the patent EP 0 825 464 of the applicant.

The patent EP 0 825 464 relates to a collective microlens known as GRADISSIMO since it consists of lengths of multimode fibres with an index gradient GRAD and silica SI welded successively together and to a ribbon of monomode fibres MO, referenced 10 in Figure 4.

The invention consists of collectively "lensing" the end of this microlens.

The losses are 2.5 ± 0.05 dB in front of 60° x 50° of total divergence in far field of $1/e^2$ of the maximum intensity for working distances of 100 ± 5 µm, instead of 10.5 dB for 15 µm of working distance in front of a cleft monomode fibre.

The losses are 1.4 ± 0.05 dB in front of lasers of 21° x 21° of total divergence in far field at $1/e^2$ of the maximum intensity for working distances of 100 ± 5 µm, instead of 3.2 dB for 15 µm of working distance in front of a cleft monomode fibre.

For this example application, the method consists in first producing the microlens ribbon 10 known as "GRADISSIMO" by collective welding and cleaving of lengths of fibres with an index gradient and silica on

a ribbon of monomode fibres as described in the patent EP 0 825 464.

This ribbon is then placed, in the same collective welder as the one used for producing the "GRADISSIMO" ribbon, typically at 900 µm from the normal welding position on the optical axis. This is possible through the control (optional) which makes it possible to control the motors and the arc of the welder by RS232 interface. An electric arc is then sent, and makes it possible to round the end of the lengths of fibres with an index gradient as illustrated in Figures 3 and 4.

The diameter of the hemisphere depends on the electric arc/fibre distance and the electrode discharge current.

By way of example the Sumitomo type T62 welder was used.

Then there was obtained collectively a ribbon of microlenses which is hereinafter referred to as "SUPERGRADISSIMO", having a hemispherical end as illustrated in Figures 4 and 5 making it possible to improve the coupling level in front of arrays of active components such as lasers, semiconductor amplifiers or photodiodes for example.

The fibres being situated far from the hot point, only the core of the fibre with a gradient index is melted so that the outside diameter of 125 µm is maintained over the entire length of the microlens, including at its end.

Here are a few example embodiments from a ribbon with 4 channels F1, F2, F3, F4:

Example 1

The coupling of a "supergradissimo" ribbon was effected in front of a BRS laser with a wavelength 1.301 µm of 60° x 50° of total divergence in far field at $1/e^2$ of the maximum intensity.

The measuring conditions were as follows:

T° = 21°C, polarisation current I = 42 mA, reference power of the laser 10,000 µW.

The results are illustrated by the following table:

| Channel (1 fibre = one channel) | Welding losses silica/ index gradient (dB) | Length of silica (µm) | Welding losses (silica/ monomode) | Length of index gradient (µm) | Radius of hemisphere (µm) | Coupling losses (dB) | Working distance (µm) |
|---|---|---|---|---|---|---|---|
| F1 | 0.06 | 544.00 | 0.04 | 357.19 | 68 | 2.56 | 53.5 |
| F2 | 0.02 | 546.50 | 0.03 | 358.00 | 68 | 2.59 | 54.3 |
| F3 | 0.07 | 546.12 | 0.02 | 354.45 | 68 | 2.55 | 53.3 |
| F4 | 0.03 | 546.12 | 0.05 | 357.19 | 68 | 2.52 | 54.2 |

Example 2

The coupling of a "supergradissimo" ribbon was effected in front of a BRS laser 1.310 µm of 21° x 21° of total divergence in far field at $1/e^2$ of the maximum intensity.

The measuring conditions were as follows:

T° = 22°C, polarisation current I = 72.6 mA, reference power of the laser 10,000 µW.

The results are illustrated by the following table:

| Channel | Welding losses | Length of | Welding losses | Length of | Radius of | Reflect ivity | Coupling losses | Working distance |
|---|---|---|---|---|---|---|---|---|

| | silica/ index gradient (dB) | silica (μm) | (silica/ monomode) | index gradient (μm) | hemi-sphere (μm) | at end of fibre (dB) | (dB) | (μm) |
|---|---|---|---|---|---|---|---|---|
| F1 | 0.05 | 275.00 | 0.05 | 279.00 | 82 | -39.3 | 1.45 | 102.40 |
| F2 | 0.04 | 275.00 | 0.02 | 281.00 | 80 | -40.1 | 1.41 | 107.60 |
| F3 | 0.03 | 274.50 | 0.06 | 281.00 | 83 | -41.9 | 1.38 | 107.80 |
| F4 | 0.04 | 274.00 | 0.02 | 282.00 | 81 | -39.3 | 1.42 | 105.00 |

By way of comparison, because of its rounded profile, the reflectivity measured at the end of the fibre by means of a reflectometer of the WIN-R type from Photonétics is typically -40 dB instead of -14.7 dB for a cleft fibre.

In addition, the great working distance limits the power reinjected into the laser diode after reflection on the fibre. This is very important for applications of the semiconductor amplifier type or lasers with external cavities for which the stray reflections interfere with the functioning.

A low-cost collective "lensing" method has just been described which makes it possible to improve the coupling between the arrays of active components and ribbons of monomode fibres compared with the prior art (up to 1.5 dB of losses) for large working distances (up to 100 μm). And this in a homogeneous manner over ribbons of fibres, it being understood of course that this is merely an example with 4 channels.

The applications of the invention in the field of telecommunications fit just as well in distribution networks for their collective and low cost aspect and in transmission networks because of their high coupling performances and their low reflectivity level. The

large working distances which they offer are an advantage for all applications, and are in fact less critical to position and greatly reduce the influence of Fresnel reflections.

Reference can be made to the table annexed to the description which illustrates results obtained for the radius of the spheres as a function of the distance between the fibre ribbon and the hot point of the electrodes E1, E2, the current sent to the electrodes in arbitrary units and the electrode discharge time. The margin indicated for each radius corresponds to the scattering of the values on the ribbon.

| Sample N° | Distance ribbon/ electrodes (µm) | Current (µ.a) | Electrode discharge time | Radius of hemisphere (µm) |
|---|---|---|---|---|
| 298 | 920 | 60 | 7 | 82 ± 5 |
| 297 | 920 | 60 | 7 | 80 ± 5 |
| 302 | 920 | 60 | 6 | 95 ± 5 |
| 288 | 910 | 60 | 5 | 110 ± 5 |
| 293 | 910 | 60 | 7 | 80 ± 5 |
| 285 | 910 | 59 | 7 | 90 ± 5 |
| 277 | 910 | 60 | 4 (3 impacts) | 75 ± 5 |
| 287 | 910 | 58 | 5 (2 impacts) | 80 ± 5 |
| 295 (ex.2) | 900 | 60 | 6 | 82 ± 5 |
| 294 | 900 | 60 | 6 | 90 ± 5 |
| 290 | 900 | 60 | 7 | 85 ± 5 |
| 292 | 900 | 60 | 8 | 90 ± 5 |
| 291 | 900 | 59 | 9 | 85 ± 5 |
| 296 | 900 | 60 | 6 (2 impacts) | 78 ± 5 |
| 287 | 890 | 56 | 5 | 110 ± 20 |
| Test | 890 | 55 | 3 | 100 ± 30 |
| Test | 850 | 63 | 5 | 75 ± 5 |
| 286 (ex.1) | 840 | 63 | 5 | 68 ± 0 |
| Test | 830 | 63 | 5 | 70 ± 5 |
| Test | 730 | 63 | 5 | Not homogeneous |
| Test | 400 | 50 | 2 | Not homogeneous |
| Test | 350 | 45 | 3 | No rounded part |
| Test | 300 | 50 | 2 | Not homogeneous |
| Test | 200 | 50 | 2 | Not homogeneous |
| Test | 200 | 30 | 2 | No rounded part |
| Test | 20 | 50 | 2 | Large lenses not homogeneous |

Beams are obtained with a hemispherical end of between 68 and 110 µm with a homogeneity of ± 5 µm on the 4 channels of the ribbon for distances between hot point and ribbon ranging from 830 to 920 µm. Ribbons 286 and 295 are the subject of embodiments presented respectively in Examples 1 and 2.

CLAIMS

1. A method for the collective production of microlenses at the end of a set of parallel optical fibres, characterised in that it comprises a step of heating the end of all the fibres (F) in the set by means of an electric arc (A), the plane or planes in which the fibres are situated being for this purpose parallel to the line (X) of the hottest points of the electric arc and the edge or edges of this or these planes on which the ends of the fibres are situated being distant from this in order to round all the fibre ends homogeneously and simultaneously to obtain all the microlenses.

2. A method for the collective production of microlenses according to Claim 1, characterised in that the distance (d) between the ends of the optical fibres and the line of the hottest points is between 850 micrometres and 950 micrometres.

3. A method for the collective production of microlenses according to Claim 1 or 2, characterised in that the set of optical fibres consists of a ribbon (10).

4. A method for the collective production of microlenses according to Claim 3, characterised in that the ribbon comprises monomode fibres (MO) whose terminations comprise a length of silica (SI) welded to a length of fibre with an index gradient (GRAD), the microlenses (L1, Ln) being produced at the end of the lengths of fibres with an index gradient (GRAD).

ABSTRACT

The invention relates to a method for the collective production of microlenses at the end of a set of aligned optical fibres. According to the invention the method consists in heating the end of all the fibres (F) by means of an electric arc (A) in order to form the microlenses, the plane in which the ends of the fibres are situated being distant (d) from the line (X) of the hottest points in the electric arc in order to round their end homogeneously.

The invention applies to the production of optical and optoelectronic modules.

Figure 3.

10/009199

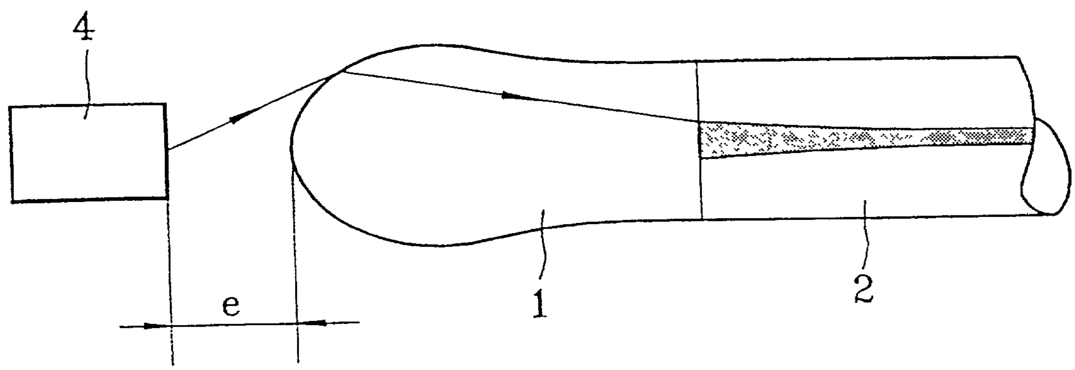



FIG. 1

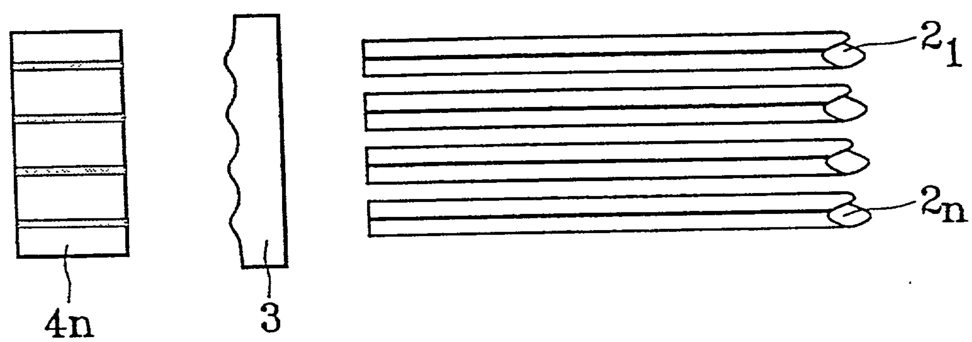



FIG. 2

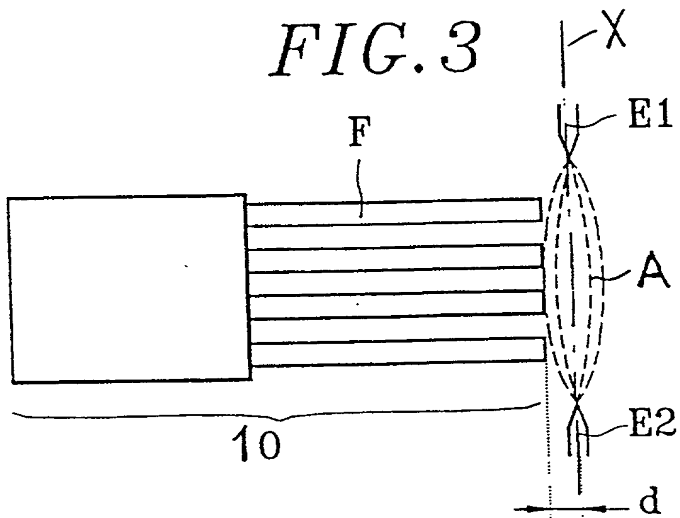



FIG. 3

10/009199

FIG. 4

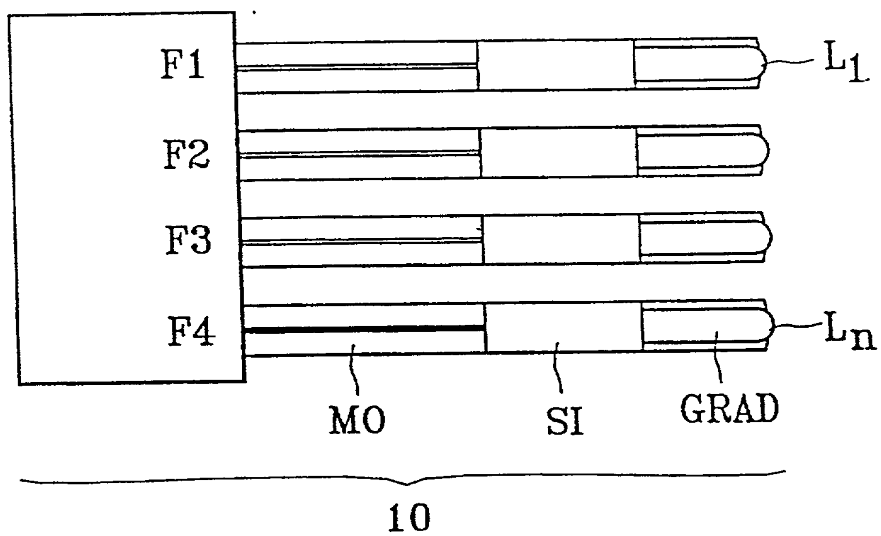
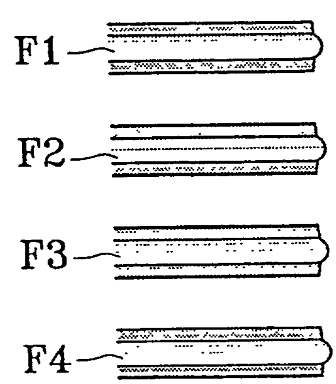



FIG. 5



015161.US/PCT

FTR2D/03179

# COMBINED DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION (37 CFR 1.63) and POWER OF ATTORNEY

☐ Declaration Submitted with Initial Filing

**OR**

☑ Declaration Submitted after Initial Filing (surcharge (37 CFR 1.16(e)) required)

**Attorney Docket Number: 136.166**
**First Named Inventor: Monique Thual**
***COMPLETE IF KNOWN***
Application Number: 10/009,199
Filing Date: December 6, 2001
Group Art Unit: Not Known
Examiner Name: Not Known

**As a below named inventor, I hereby declare that:**

My residence, mailing address, and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

**A METHOD FOR THE COLLECTIVE PRODUCTION OF MICROLENSES AT THE END OF A SET OF OPTICAL FIBRES OF THE FIBRE RIBBON TYPE**

the specification of which

☐ is attached hereto

OR

☑ was filed on December 6, 2001 as United States Application Serial No. 10/009,199 and was amended on December 6, 2001, and is a national phase application of PCT International application No. PCT/FR00/01593.

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment specifically referred to above.

I acknowledge the duty to disclose information which is material to the patentability as defined in 37 CFR 1.56, including for continuation-in-part applications, material information which became available between the filing date of the prior application and the national or PCT international filing date of the continuation-in-part application.

I hereby claim foreign priority benefits under 35 U.S.C. 119(a)-(d) or 365(b) of any foreign application(s) for patent or inventor's certificate, or 365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or any PCT international application having a filing date before that of the application on which priority is claimed.

| Prior Foreign Application(s) | | | Priority Not Claimed | Certified Copy Attached? |
|---|---|---|---|---|
| 99 07289 | France | June 9, 1999 | ☐ | ☐ Yes ☑ No |
| (Number) | (Country) | (Foreign Filing Date) | | |
| PCT/FR00/01593 | France | June 8, 2000 | ☐ | ☐ Yes ☐ No |
| (Number) | (Country) | (Foreign Filing Date) | | |
| | | | ☐ | ☐ Yes ☐ No |
| (Number) | (Country) | (Foreign Filing Date) | | |

☐ Additional foreign application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto:

I hereby claim the benefit under 35 U.S.C. 119(e) of any United States provisional application(s) listed below.

| | | |
|---|---|---|
| (Application Number) | (Filing Date) | ☐ Additional provisional application numbers are listed on a supplemental priority data sheet PTO/SB/02B attached hereto. |

10/009,199
136.166

(4)

# COMBINED DECLARATION – Utility or Design Patent Application and POWER OF ATTORNEY

______________________ ______________________
(Application Number) (Filing Date)

As a below-named inventor, I hereby appoint the registered practitioners named below as my/our attorney(s) or agent(s) to prosecute this application, and to transact all business in the Patent and Trademark Office connected therewith:

James E. Nilles, Reg. No. 16,663
Stephen Michael Patton, Reg. No. 36,235
Thaddeus C. Stankowski, Reg. No. 45,522
Matthew M. Eslami, Reg. No. 45,488

Direct all telephone calls to James E. Nilles at telephone number (414) 276-0977, facsimile number (414) 276-0982.
Direct all correspondence to: James E. Nilles
NILLES & NILLES, S.C.
Firstar Center, Suite 2000
777 East Wisconsin Avenue
Milwaukee, WI 53202-5345

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under 18 U.S.C. 1001 and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

1-00

**Full name of Sole or First Inventor:** ☐ A petition has been filed for this unsigned inventor

Given Name (first & middle [if any]) and Family Name or Surname: Monique Thual
Inventor's Signature: Monique THUAL Mthual Date: 8 mars 2002
Residence (city, state, country): Trebeurden, France FRX Citizenship: French
Mailing Address: 5, rue de Liors Eron
(city, state, zip, country): F-22560 Trebeurden, France

2-00

**Full name of Second Inventor, if any:** ☐ A petition has been filed for this unsigned inventor

Given Name (first & middle [if any]) and Family Name or Surname: Philippe Chanclou
Inventor's Signature: Philippe Chanclou Date: 21 mars 2002
Residence (city, state, country): Louannec, France FRX Citizenship: French
Mailing Address: ~~49, rue Kernu~~ 2 hent Krech nevez - Sovel
(city, state, zip, country): ~~F-22700 Louannec, France~~ F-22300 Lannion, France

3-00

**Full name of Third Inventor, if any:** ☐ A petition has been filed for this unsigned inventor

Given Name (first & middle [if any]) and Family Name or Surname: Jean Lostec
Inventor's Signature: Jean Lostec Date: 26 mars 2002
Residence (city, state, country): Prat, France FRX Citizenship: French
Mailing Address: 14, route de l'Escoben
(city, state, zip, country): F-22140 Prat, France

G:\Data\CLIE